BBC RD 1989/17

Engineering Division Report

A waveform capture and storage unit and its use for investigating disturbances on digital transmission links

A. Oliphant, M.A., C.Eng., M.I.E.E., Research Department
R.E. Vialls, Research Department
R.M. Inman, B.Eng., Transmission Engineering Department

Research Department, Engineering Division
THE BRITISH BROADCASTING CORPORATION

BBC RD 1989/17

A WAVEFORM CAPTURE AND STORAGE UNIT AND ITS USE FOR INVESTIGATING DISTURBANCES ON DIGITAL TRANSMISSION LINKS

A. Oliphant, M.A., C.Eng., M.I.E.E. (Research Department)
R.E. Vialls (Research Department)
R.M. Inman, B.Eng. (Transmission Engineering Department)

Summary

This Report describes a unit to capture analogue waveforms and store them digitally. It was designed for investigation of bitstream disturbances in the BBC's PCM audio distribution network which uses an 8448 kbit/s multiplex of digital audio signals carried on analogue video circuits.

The unit has been successfully used in the diagnosis and subsequent elimination of bitstream disturbances that had given rise to complaints from listeners; several examples of its use so far are given and other applications are suggested.

Engineering Division,
BRITISH BROADCASTING CORPORATION

(EL-202)

1989

© British Broadcasting Corporation

No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without prior permission.

A WAVEFORM CAPTURE AND STORAGE UNIT AND ITS USE FOR INVESTIGATING DISTURBANCES ON DIGITAL TRANSMISSION LINKS

1. Introduction 1

2. A First Solution — A Recirculating Line Store 1

3. The 'VISADS' Equipment 2

   3.1 Specification 3

   3.2 Outline of the design 3

   3.3 Mechanical construction 4

4. Operational Use of VISADS 5

   4.1 'Fingerprinting' 5
      4.1.1 Interference introduced at baseband onto coaxial cables 6
      4.1.2 Equipment that is faulty, but does not fail completely 6
      4.1.3 Interference on equipment power supplies 6

   4.2 Tracing other faults 7

   4.3 Measurement of eyeheight 7

   4.4 Other uses 8

5. Conclusions 8

(EL-202)

© BBC 2005. All rights reserved. Except as provided below, no part of this document may be reproduced in any material form (including photocopying or storing it in any medium by electronic means) without the prior written permission of BBC Research & Development except in accordance with the provisions of the (UK) Copyright, Designs and Patents Act 1988.

The BBC grants permission to individuals and organisations to make copies of the entire document (including this copyright notice) for their own internal use. No copies of this document may be published, distributed or made available to third parties whether by paper, electronic or other means without the BBC's prior written permission. Where necessary, third parties should be directed to the relevant page on BBC's website at http://www.bbc.co.uk/rd/pubs/ for a copy of this document.

A WAVEFORM CAPTURE AND STORAGE UNIT AND ITS USE FOR INVESTIGATING DISTURBANCES ON DIGITAL TRANSMISSION LINKS

1. INTRODUCTION

In the early 1970s the BBC started distributing sound programmes in PCM form from studios to transmitters as a digital multiplex. Early equipments provided thirteen high quality audio channels in a bitstream of 6336 kbit/s; these are now being replaced with NICAM equipments providing 24 high quality channels in a bitstream at the CCITT hierarchical bit rate of 8448 kbit/s. This PCM multiplex equipment allows the BBC to transmit very high quality sound signals to the listener.

The digital signals are routed over analogue video circuits, some rented from British Telecom (BT), some provided by the BBC. These circuits were not engineered for use with PCM, but their characteristics are such that they normally give perfect transmission of the digital signals. But from its inception the PCM multiplex system has suffered from occasional random short-duration breaks affecting all channels of a multiplex. These breaks may be perceived by the listener as loud clicks, which have given rise to a number of complaints from the general public. It may be noted in passing that this form of failure is characteristic of digital transmission. As interference increases, an analogue transmission degrades gradually whereas a digital transmission remains perfect until very severe interference causes complete failure.

As the PCM distribution system achieved wider coverage, the bitstream breaks were perceived as a more and more serious problem: they affected both BT and BBC links engineered in different ways. An investigation was therefore started by Transmission Technical Investigations (TTI) Section of Transmission Engineering Department (TED). This Report describes some aspects of the investigation and in particular the use of a specially designed waveform capture and storage unit. This unit and the techniques of investigation it opens up may have other applications, and it is one object of this Report to draw them to the attention of a wider audience of engineers.

It proved impossible to find the causes of the bitstream breaks using conventional test equipment. Their occurrence could be logged using the monitoring (error detection) systems in the digital multiplex — sample parity and a cyclic redundancy check. And the audible effect could be recorded using equipment developed by Design and Equipment Department (MASS-ADZE — essentially a digital audio delay line feeding a cassette recorder), triggered by the PCM monitoring system. Logic analysers showed that there were breaks in the digital bitstream before the audio decoder. But these techniques could only provide evidence of the existence of a fault; they gave no information on the possible causes.

Clearly, what was needed was a means of recording the waveform of the bitstream coming in from the link, before the regenerator that is the first stage of decoding. Storage oscilloscopes were considered, but none on the market when the investigation started had the storage capacity and flexibility needed*. It was at this point that TTI engineers asked Research Department for suggestions to help further the investigation.

2. A FIRST SOLUTION — A RECIRCULATING LINE STORE

The first suggestion from Research Department was to treat the incoming bitstream as an analogue video waveform, to convert it to digital form using a video analogue-to-digital converter (ADC) and pass it through a digital store to a digital-to-analogue converter (DAC). On receipt of a trigger pulse indicating a bitstream break from the PCM monitoring system the store would be set to recirculate, capturing a section of the bitstream for examination on a general-purpose oscilloscope and allowing photographs to be taken of details. This arrangement is shown in Fig. 1.

It turned out that a recirculating store with a capacity adjustable up to 115 μs already existed at Research Department; it had been designed and built** as a laboratory tool to examine the effect of bit-rate-reduction processing on individual lines of a video signal. The recirculating store was loaned to TTI with a self-contained video analogue-to-digital and digital-to-analogue converter (ADC/DAC) unit as shown in Fig. 2.

This equipment was used in the summer of 1986 to carry out an investigation of the link to the Wenvoe transmitter in South Wales†. This link was chosen because many of the complaints from the

---

* Since the equipment described in this Report was built, a digital storage oscilloscope with sufficient storage and flexibility has become available. It is made by the Swiss company LeCroy. But it is expensive - because of its stringent specification and great flexibility - and requires a dedicated Personal Computer to make permanent records.

** by M.J. Knee

† by R.G. Seville and R. Reich of TTI

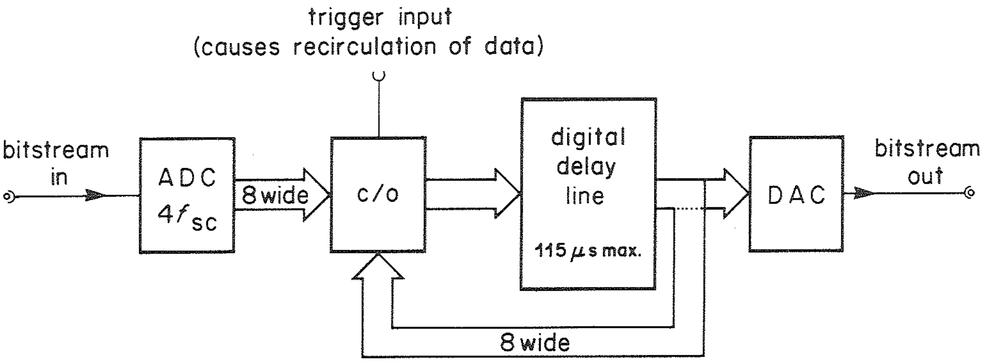


Fig. 1
Block diagram of the recirculating line store.

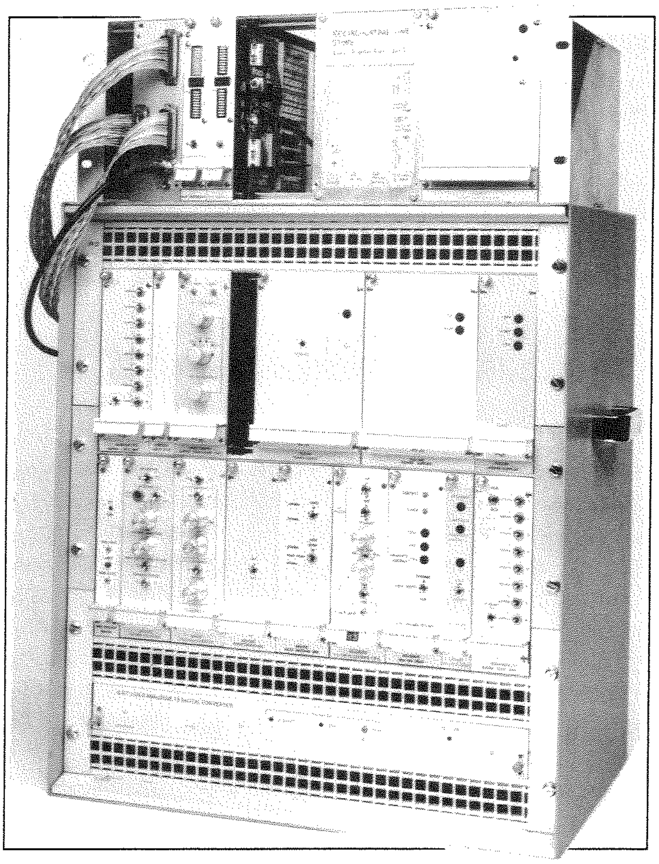


Fig. 2 - The recirculating line store (top) and ADC/DAC unit loaned to TTI in 1986.

public concerned Wenvoe or other transmitters that are fed by rebroadcast link from Wenvoe. After some difficulties with obtaining a trigger pulse from the monitoring system suitably timed to capture the bitstream break that caused the disturbance, a number of bitstream breaks were captured and photographed.

These photographs showed that there were at least three different types of disturbance to the bitstream: genuine short breaks — thought to be caused by equipment changeovers at intermediate stations (Fig. 3a), impulsive interference (Fig. 3b), and DC bounce — which caused a break when amplifiers limited and then recovered due to AC coupling (Fig. 3c). Once identified, the problem of DC bounce was quickly eliminated by modifying the input time constants of the video distribution amplifiers carrying the PCM signal.

Although some bitstream breaks were captured, the recirculating line store was not a complete solution to the problem of finding the causes of bitstream breaks. The equipment shown in Fig. 2 is large and cumbersome; it is not user-friendly, since it was not designed for this application; and it can store only one event during unattended operation. Furthermore, the investigation at Wenvoe suggested some refinements: more than 115 μs of storage was needed to record events that consisted of bursts of interference; more comprehensive triggering facilities were needed to give the user control over the start point of the recording with respect to the trigger pulse; detailed examination of the captured waveform required a dual-timebase oscilloscope, which is not available at most transmitter sites, so a variable replay facility was needed; and finally the ADC input and output filters caused some distortion of the bitstream.

However, the investigation at Wenvoe showed that the technique could be used to record the bitstream disturbances and that these recordings could be used to pinpoint their causes. To quote an engineer at Wenvoe on using the experimental equipment, "marvellous...at last we can *see* the problem". And, most important, some of the problems could be eliminated to give improved quality to the listener. Research Department therefore agreed to design and build special-purpose equipment based on the same waveform capture and storage principle, but with a specification that would take account of the shortcomings in the recirculating line store equipment revealed by the investigation at Wenvoe.

3. THE 'VISADS' EQUIPMENT*

The equipment built by Research department is known colloquially within TTI as VISADS, an acronym for **VI**deo **S**torage **A**nd **D**isplay **S**ystem.

---

* R.E. Vialls, then a Pre-University Trainee at Research Department, was responsible for the design, construction and testing of the prototype VISADS equipment.

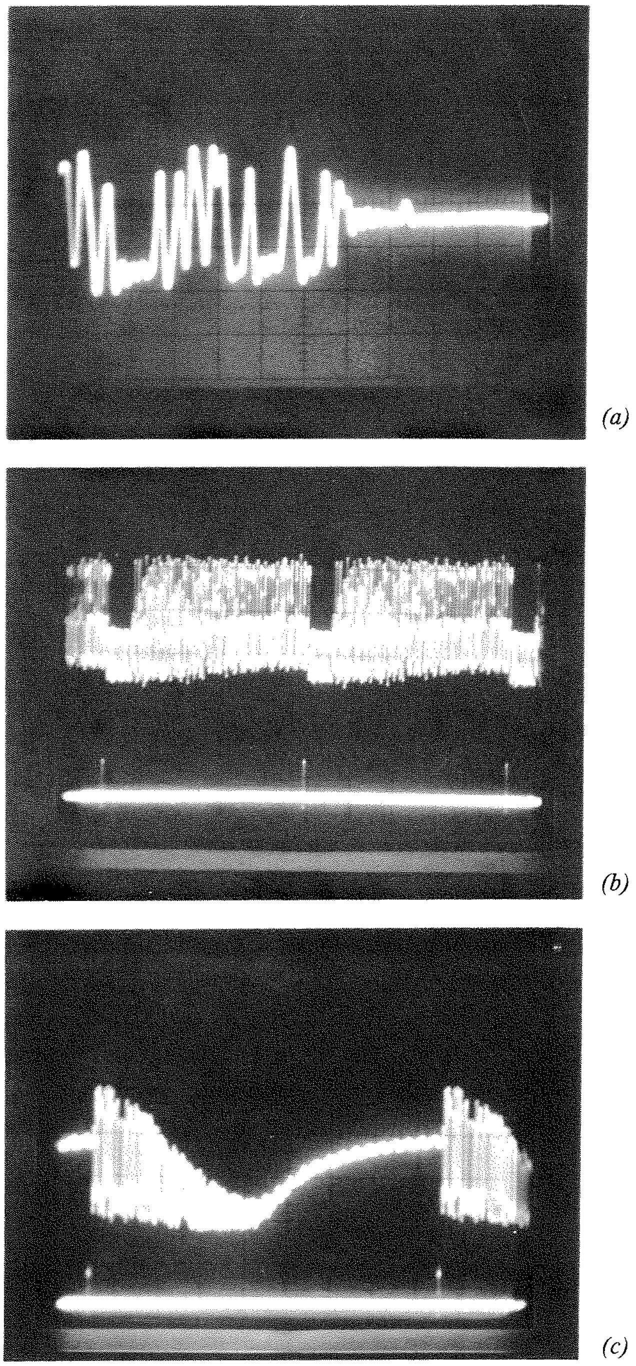


Fig. 3 - Waveform photographs taken during the investigation at Wenvoe in 1986.

(a) Waveform break thought to have been caused by an equipment changeover at an intermediate station.
(b) Impulsive interference.
(c) Waveform break caused by DC bounce.

The pulses on the bottom trace in (b) and (c) show the length of the store; thus these photographs repeat some parts of the event.

3.1 Specification

An initial design study showed that a specification incorporating the improvements suggested above could be further enhanced without extra complexity.

In the recirculating line store equipment, some distortion of the bitstream had been noticed from the 5.5 MHz low-pass filters in the ADC and DAC units. These filters are needed to prevent aliasing distortion caused by input frequencies greater than half the sampling frequency of the unit. In the VISADS unit the filters are scaled to 7.5 MHz and the sampling frequency is chosen to be 20.25 MHz.

The store length was originally specified to be at least 1 ms for each event recorded, but the preliminary design study showed that the RAMs chosen for the main store would give a slightly longer storage time of 1.62 ms.

The specification called for an interface port so that data from a captured event could be stored on a floppy disk in a separate disk drive. However the design study showed that it would be easier to incorporate a disk drive in the equipment. VISADS can store eight events in RAM and a further eight events on floppy disk. In unattended use it can capture eight events in the RAM store, then transfer these events to disk, and then capture another eight events in RAM, thus capturing sixteen events in all.

The unit records with each event the date and time at which it happened. To do this, it contains a real-time clock with a numerical display on the front panel. The clock is powered from a battery that is recharged whenever the unit is connected to the mains; the battery will keep the clock running for about one year without recharge.

In the 'capture' mode the delay between the trigger pulse and the point at which the unit stops recording and starts recirculating can be adjusted over the full length of the store. Because the unit is continually recording, the store contains the previous 1.62 ms of the input waveform when the trigger pulse is detected. Thus the unit can store 1.62 ms of the input waveform starting at any time up to 1.62 ms before the trigger pulse. In the 'replay' mode the unit can replay a segment of the stored waveform of any length; the start and duration of the replayed segment are set by front panel controls. However the data is always replayed at the same sampling frequency as was used for capturing it, so an oscilloscope can be used for making accurate timing measurements on the replayed waveform.

3.2 Outline of the design

A block diagram of the VISADS equipment is shown in Fig. 4. Each box in the block diagram represents a separate unit in the equipment as built.

The input waveform is converted to digital form in a standard video ADC board (based on a monolithic 8-bit ADC), with a 7.5 MHz input filter as noted above. The store board is based on eight 62256 32K × 8 RAMs; the input data is demultiplexed eight ways in order to meet the specification for the access time of the RAM. The store real-time record and replay addresses are generated and the store is controlled by the store control board, which also contains a crystal oscillator to generate the 20.25 MHz sampling clock. Trigger delay, replay start, and replay duration are set by controls on the front panel — pressbuttons for coarse adjustment and rotary encoders for fine adjustment. The outputs of these controls are interfaced to the store control board by the numerical input board, which also drives numerical displays on the front panel to show the values selected. The waveform output to an oscilloscope is through a standard video DAC, again with scaled filters.

The overall control of the unit is performed by the processor board which is based on a 6502A processor. This board controls the disk drive directly and interfaces with some of the front panel controls and the store and store control boards via the computer interface board. The disk interface works on the same standard of disk format as the BBC Microcomputer, so that the data on the disks can be analysed using a BBC Microcomputer. To achieve this, the processor board contains a disk controller sub-unit from a BBC Microcomputer with some external components, arranged so that the hardware of the processor board resembles as closely as possible the hardware of a BBC Microcomputer; the few differences that remain (such as the lack of a keyboard) are concealed from the disk system with software. The disk drive is a standard 5-inch double-sided 80-track floppy disk drive suitable for connection to a BBC Microcomputer. The processor board also contains a real-time clock with registers for seconds, minutes, hours, day of the week, day of the month, month, and year; the real-time clock is powered by a separate battery back-up board.

The front panel is shown in Fig. 5. It includes a display of date and time, displays of trigger delay, replay start, and replay duration — all in microseconds rather than in clock periods — and the controls for setting them, and pushbuttons that control the operation of the unit, together with status indicator lights.

3.3 Mechanical construction

The prototype unit consists of standard ADC and DAC cards plus five specially designed cards, the battery backup unit for the real-time clock, a main power supply, and the disk drive; there is also some

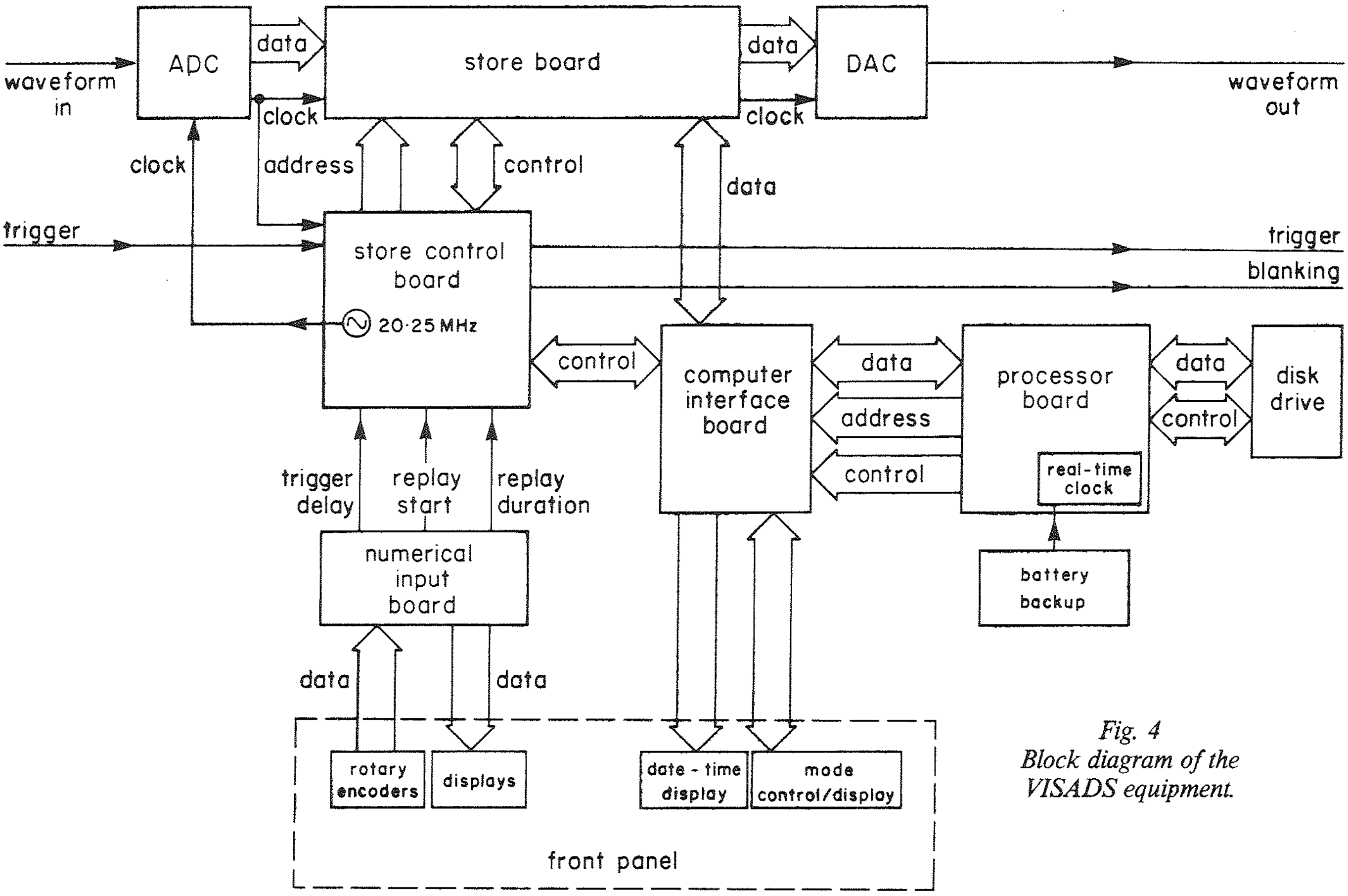


Fig. 4
Block diagram of the VISADS equipment.

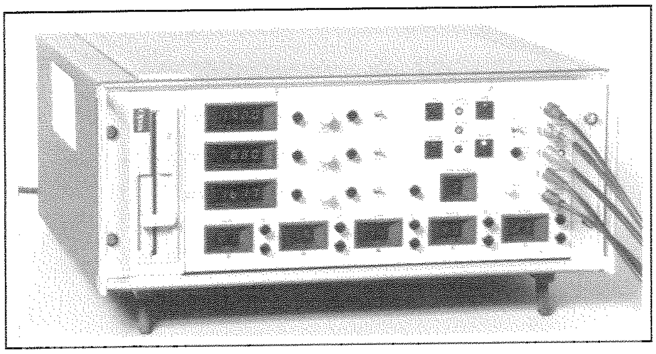


Fig. 5 - The VISADS unit, showing the front panel.

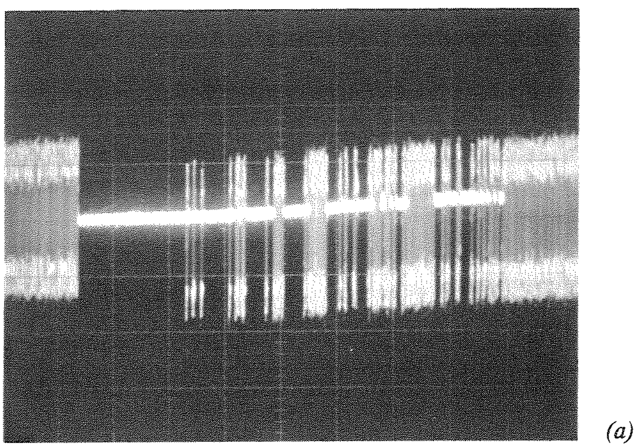
extra circuitry on the rear of the front panel. These are all contained in a 19-inch rack with a hinged front panel. The cards are inserted from the back of the unit so that the backplane wiring is immediately behind the hinged front panel. Some of the interconnections between boards are implemented using D-type connectors on the front panels of the cards linked with ribbon cables. In the prototype unit the specially designed cards, the backplane, and the front panel circuitry were hand wired; however a second unit was made later with printed circuits for the backplane and the front panel, and machine-wired boards.

4. OPERATIONAL USE OF VISADS

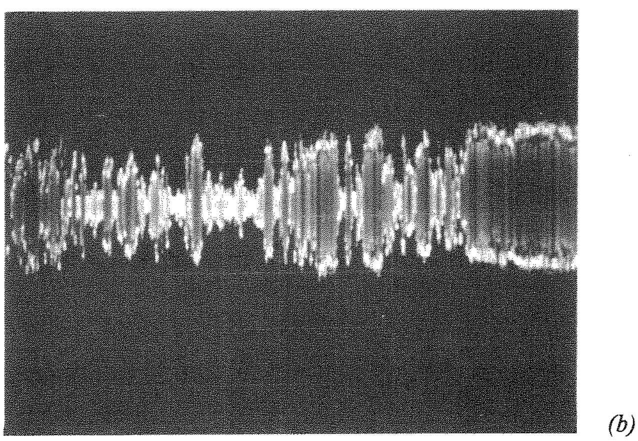
4.1 'Fingerprinting'

As the first stage of an investigation into bitstream disturbances, it is desirable to eliminate as many likely causes as possible. The manifestation of the interference can often be a considerable distance from the cause of it. Furthermore, the number of potential causes can be immense, particularly on a multi-hop radio link. Before VISADS was available, disturbances caused by different sources were indistinct. So not only did it take a great deal of time to locate the cause, but the search process would have to be repeated at every site. When the disturbance was due to a number of different sources, the problem became very cumbersome! VISADS has enabled the TTI Network's Engineers to build up a collection of 'fingerprints' of bitstream interference patterns, following a large number of site visits made throughout the country. It is now possible to arrive at a site, and collect a number of typical disturbances with VISADS. The disturbance patterns can then be compared to the library of known causes. Obviously not all sources of interference can be identified by fingerprinting, but this technique will usually eliminate a large number of potential causes.

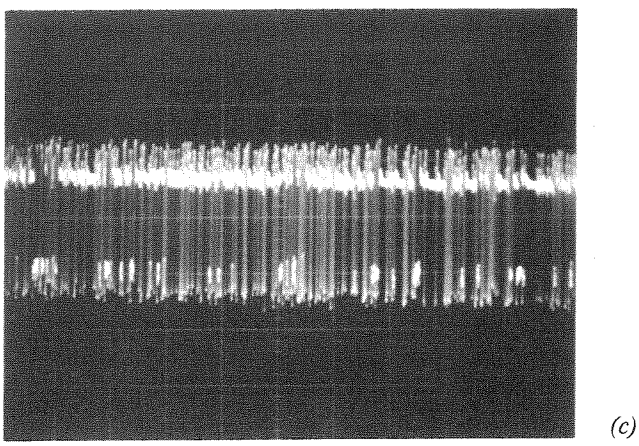
The disturbances may be caused by routine action, such as base-band switching or waveguide change-overs; these types of disturbances are acceptable if they are not too frequent. Typical examples are shown in Fig. 6. The more serious disturbances arise from the addition of extraneous signals to the bitstream. By examining the nature of these signals, it



(Horizontal scale: 100 µs/div)



(Horizontal scale: 50 µs/div)



(Horizontal scale: 20 µs/div)

Fig. 6 - Waveform disturbances caused by routine switching.

(a) Baseband switching.

Baseband changeover between A and B regenerators at Holme Moss, observed at Belfast.

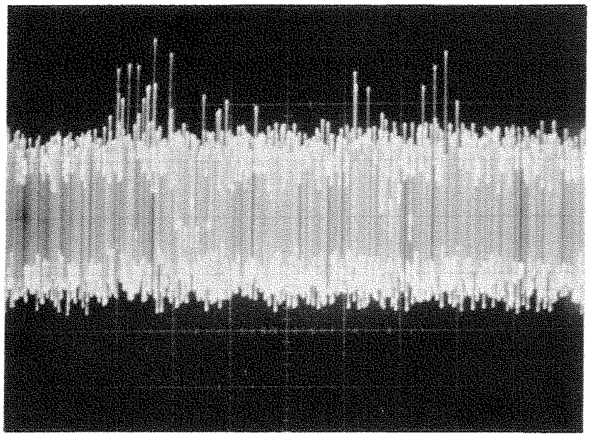
(b) and (c) Waveguide changeover.

Waveguide changeover at Swains Lane observed at Holme Moss. Fig. 6(b) shows the waveform at the regenerator input; Fig. 6(c) shows the regenerator output.

is possible to narrow the field of search immensely. This type of interference has usually been found to fall into one of three broad areas discussed in the following sub-sections.

4.1.1 Interference introduced at baseband onto coaxial cables

Coaxial cables may run within a single site (tie-lines) or may form part of the national distribution network. Interference on these cables tends to be single-polarity impulses, sometimes isolated, sometimes in bursts. An example is shown in Fig. 7.



(Horizontal scale: 20 μs/div)

Fig. 7 - Impulsive interference picked up on a coaxial cable link.

Interference on coaxial cables has often been traced to switching of power circuits running close to coaxial cables carrying the bitstream. However, a current investigation in the Manchester area has shown that there is a correlation between the incidence of this type of interference and working hours: reductions are evident at lunch times and at the times of the mid-morning and mid-afternoon breaks. The suspected cause in this case is crosstalk from telephone dialling pulses on audio pairs running through the same tube.

4.1.2 Equipment that is faulty, but does not fail completely

The most common examples of this category are pulse distribution amplifiers and SHF radio link equipment; examples of both are shown in Fig. 8.

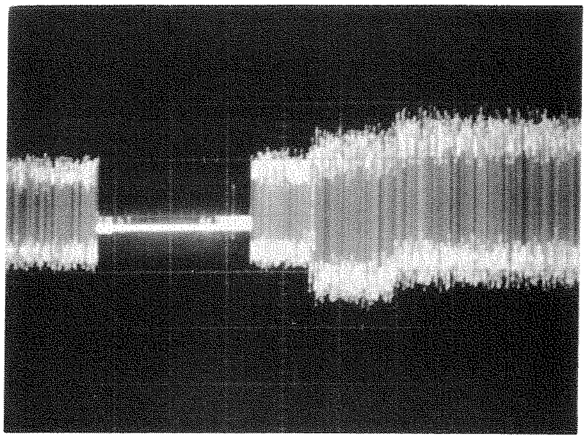
4.1.3 Interference on equipment power supplies

This category may be sub-divided into two further groups:

(a) interference present on the mains supply, often caused by the switching of power circuits (particularly inductive loads) on the same mains feed. Fig. 9 shows an example: the interference on the bitstream occurred only when the fluorescent lights were switched on!

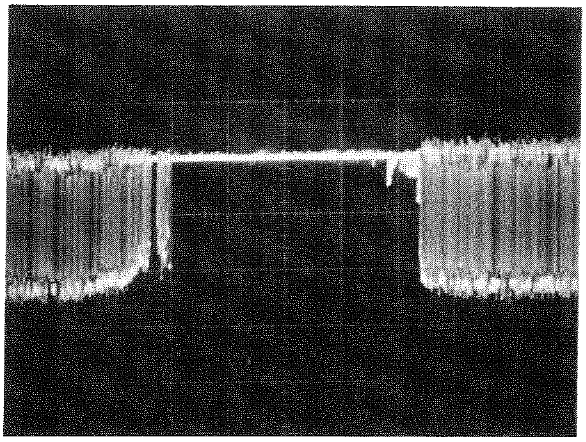
(b) interference on the low-voltage supplies to PCM transmission equipment. This is a particular problem when one power supply unit supplies a number of other units which may not be adequately decoupled from each other.

Many of the disturbances are of too short a duration to be seen on a conventional oscilloscope, and in any case it would not be possible to examine the trace continuously. VISADS can be used to examine the DC supply rails of the amplifiers, using errors on the bitstream to trigger it. Usually, the supply rail will be capacitively coupled to the VISADS input, with attenuation if necessary. Using this method, TTI Engineers have managed to trace the cause of serious bitstream interference to perturbations on the DC supply rails.



(a)

(Horizontal scale: 50 μs/div)



(b)

(Horizontal scale: 50 μs/div)

Fig. 8

(a) Interference caused by a faulty distribution amplifier.

(b) Interference caused by the momentary failure of an SHF link.

Fig. 10 shows two typical examples of interference on amplifier supply rails that were resulting in bitstream corruption. Fig. 10(a) shows ringing that was traced to the de-energisation of a relay in an adjacent bay. Close examination of the narrow pulses shown in Fig. 10(b) showed that they corresponded to TV line frequency: a sync pulse generator with defective supply filtering was identified as the culprit.

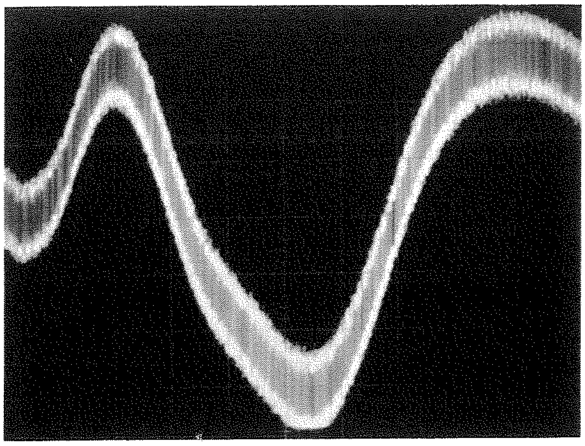
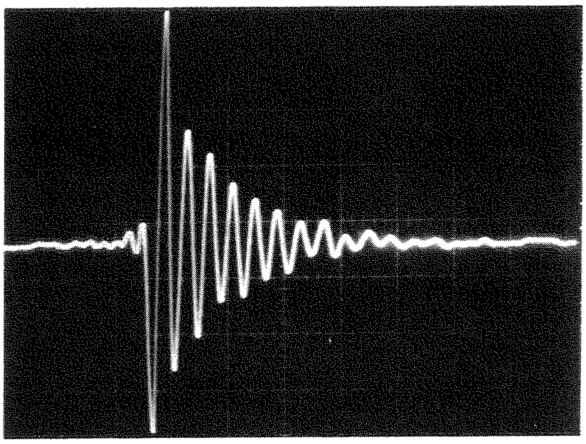
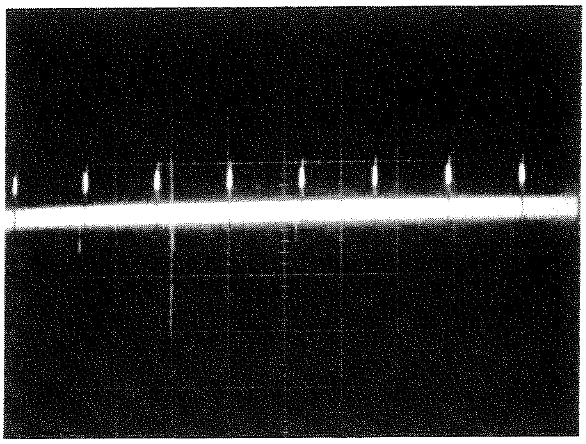

(Horizontal scale: 100 μs/div)

Fig. 9 - Mains-borne interference from an adjacent lighting circuit.


(a)

(Horizontal scale: 0.5 μs/div)


(b)

(Horizontal scale: 50 μs/div)

Fig. 10 - Interference on low-voltage power supplies.
(a) From de-energisation of a relay in an adjacent bay.
(b) From a TV sync pulse generator.

4.2 Tracing other faults

When interference does not correspond to a known fingerprint, and power supplies have been eliminated, VISADS can be used to localise the source by comparing recordings made at both ends of a link. When a suspected source of interference has been found, the suspicion can be confirmed by recording the bitstream whilst the suspected interfering source is stimulated.

An example of this method occurred when examining a circuit from Holme Moss to Scotland. The particularly severe interference pattern shown in Fig. 11 was present at Kirk O'Shotts, and appeared at four-hourly intervals. It was eventually attributed to a time-switch on an air compressor at a repeater station near Manchester. By cycling the time switch manually whilst recording the bitstream, the effect could be matched to the events previously recorded in Scotland, thus positively identifying the source of the disturbance.

Another example is shown in Fig. 12. Again, these disturbances were first recorded at Kirk O'Shotts. The cause was eventually identified as an alarm bell in a control room at Manchester. The bell was not connected to the same supply as the bitstream apparatus, but the interference was being introduced by electromagnetic radiation.

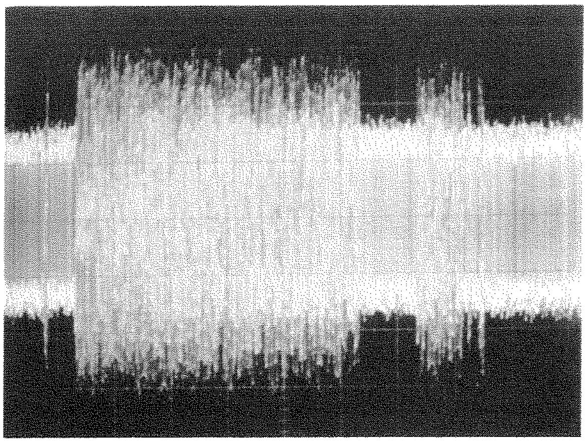
4.3 Measurement of eyeheight

Eyeheight is the only measurement of the performance of a bitstream bearing link that station staff can make as a routine measurement, and a lower limit has been prescribed for any link to guarantee satisfactory decoding. The measurement of eyeheight is therefore important as it is done at all sites.

This measurement is usually made on site with an oscilloscope. However, a program has now been written for a BBC Microcomputer* to allow the eyeheight to be calculated from stored data captured by VISADS and transferred to the computer. Some caution must be exercised when using this program as any corruption to the bitstream over the sample period will invalidate the calculated eyeheight. Therefore, a section of bitstream with no interference must be selected. Results from the program have been found to correlate remarkably well with those derived from oscilloscope measurements.

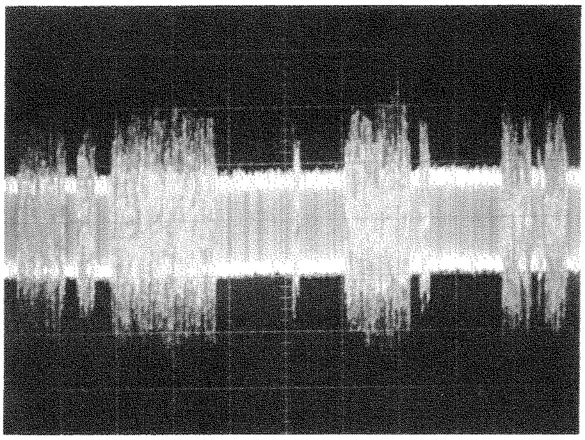
---

* The program to carry out this task was written by R. Reich and P. Lee of TED.



(Horizontal scale: 100 μs/div)

Fig. 11 - Interference recorded at Kirk O'Shotts traced to a time-switch on an air compressor.



(Horizontal scale: 100 μs/div)

Fig. 12 - Interference recorded at Kirk O'Shotts traced to an alarm bell at Manchester.

4.4 Other uses

Once an interfering source has been identified, evidence must often be collected before money and time are committed to rectifying the problem. This does not always apply to BBC sites and BBC links: in these cases minor corrective work is often carried out by, or under recommendation from, the TTI Engineers. However, when the problem is found to be on a British Telecom site or link, it is necessary to provide conclusive evidence in the form of a report when a formal complaint is made. VISADS has been very useful in providing convincing illustrations for such reports and the facility of zooming in on a selected section of a stored event is particularly useful when discussing problems with BT engineers.

It has often been found that some types of disturbance to the bitstream occur at certain times of the day or night. In these circumstances VISADS can be left unattended and will store up to 16 events; this is a most useful facility.

VISADS plays a key role in the work of curing bitstream corruption, and for this purpose it has proved indispensible. However, TTI engineers appreciate that the full potential of VISADS remains unexploited. The input bandwidth of 7.5 MHz (before roll-off) makes VISADS very flexible, and its use need not be restricted to examining PCM bitstreams. Many applications for VISADS will be found in the fields of television and data communications, but its use in these areas has not been explored.

5. CONCLUSIONS

This Report has described the collaboration between Research Department and Transmission Technical Investigations Section of Transmission Engineering Department on the development, design, and application of a waveform capture and storage unit — VISADS — for investigating bitstream disturbances in the PCM distribution system. VISADS has allowed TTI Engineers to capture transient disturbances; by examining a captured disturbance in detail, a great deal can be learned about its source, thus expediting the process of identification.

Together with the CRC error-logging apparatus, VISADS has enabled TTI Engineers to deal very successfully with serious PCM disturbances across the country, many of which had prompted numerous listener complaints. Without this valuable tool, not only would their work have been considerably more difficult, but it is very unlikely that they could have achieved such a high detection rate.

VISADS may have other applications in the fields of television and data communications; it is one object of this Report to make other engineers aware of the diagnostic possibilities of waveform capture and storage.

Printed by BBC RESEARCH DEPARTMENT, Kingswood Warren, Tadworth, Surrey, KT20 6NP